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Title: MC-15 Users Manual

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# MC-15 Users Manual

## 1. Introduction

The current iteration of field-capable neutron multiplicity counters is the Multiplicity Counter 15 tube detector (MC-15) shown in Figure 1. This was a tri-lab effort between Los Alamos National Laboratory (LANL), Lawrence Livermore National Laboratory (LLNL), and Sandia National Laboratories (SNL). The MC-15 incorporates significant improvements over previous man-portable neutron multiplicity counters of the LANL NPOD and the Ortec Fission Meter™. These improvements include finer time resolution of 100 ns, more advanced on-board computing power for near-real-time onboard analysis, a sunlight readable color touchscreen for ease of use, a USB 2.0 interface for data transfer, and hot-swappable rechargeable batteries that provide 14 hours of run time.

The layout of the MC-15 has a total of fifteen $^{3}$He tubes embedded in high density polyethylene (HDPE). Seven of the $^{3}$He tubes are aligned in a removable front panel. The remaining eight tubes are in the main body in two rows with the second, or middle, row containing six $^{3}$He tubes and the third, or last, row containing two $^{3}$He tubes.

The MC-15 records when a neutron is detected and which tube detected the neutron. The time resolution is 100 ns and this raw data is stored in a file that can be downloaded later. This list-mode file for a five min run is on the order of 100 Mbytes. Additionally, the MC-15 can analyze the data internally and display the results on the touchscreen. Data and results are stored in the internal non-volatile memory and can be exported to a USB storage device. Data collection can be started by turning the unit on, touching Collect Data, touching Start on the next screen, confirming or changing the parameters on the next screen, and touching Start. While the data collection is in process, analysis occurs, and real time summary data is displayed. More capabilities are discussed in this document.

Figure 1. MC-15 with canvas cover.

### 1.1. Purpose

This purpose of this document is to aid users of the MC-15 to achieve a better understanding of the capabilities and limitations this instrument.

### 1.2. Scope

This document is written to provide information and guidance to users of the MC-15.

### 1.3. Precautions and Limitations

#### 1.3.1. Electrical Safety

None of the procedures described in this manual require disassembly of the MC-15. However, inside each unit is a high-voltage power supply capable of 2 kV and 7 µA of current. There is 0.002 µF of capacitance, which if charged to 2 kV, would store 0.004 J. Los Alamos National Laboratory classifies this in Electrical Safety Program P101-13, Rev. 1 as Class 2.1 R&D electronic work, which requires non-energized electrical safety training. The internal lithium-ion battery has a sophisticated integral protection circuit that protects the battery from over voltage when charging (≥4.3 V to any cell), over – current when discharging (≥8.25 A), and high temperatures when discharging (>75°C).

#### 1.3.2. Additional Precautions

The MC-15 weighs 47 pounds and care is required in lifting. Each unit contains 15 Reuter-Stokes $^3$He proportional gas tubes 1 inch in diameter by 17 inches long and pressurized to 10 atm. These tubes are classified as a class/division hazard rating of 2.2 by the U.S. Department of Transportation.

## 2. Hardware Description

### 2.1. Electrical requirements

The MC-15 can be powered with a wide range of DC voltage. The standard charger that is supplied with each MC-15 gives an output of 24 V @ 3.25 A. The smallest voltage that will charge the MC-15 is 14 V at 5 amps. The maximum voltage allowed for the MC-15 is 24 V.

| | |
|---|---|
| Minimum Voltage Power Supply | 8 V @ 5 amps (no charging) |
| Maximum Voltage Power Supply | 24 V @ 3.25 Amps |

### 2.2. $^3$He Tubes and Moderator

Figure 1 shows the fully assembled MC-15 in a canvas bag, and Figure 2 shows the layout of the $^3$He tubes inside the assembled MC-15 high density polyethylene (HDPE) moderator. The dimensions of the MC-15 are 38×13×56 cm (15.0 x 5.1 x 22.0 inches), the weight is 21 kg (47 lbs) and the total volume of $^3$He at standard temperature and pressure is ~28 liters (1,710 cubic inches). The canvas bag, which can be removed if desired, contains a 0.08 cm (0.030 inch) thick sheet of cadmium on the front side of the detector facing the source to minimize the detection of neutrons that have been thermalized by the environment.

Each $^3$He tube is connected to a single preamp. This reduces the effects of dead time on the collected data. The preamps were designed at LANL and are the model KM-100. These preamps have been optimized for the $^3$He tubes in the MC-15 in order to decrease dead time and increase the maximum counting rate.

For identification purposes the tubes are numbered 1 through 15 in the configuration outlined below in Figure 2. The tubes are embedded in a high density polyethylene moderator. The density of HDPE is Class 4, which specifies a density > 0.96 g/cc per ASTM D4976-12a.

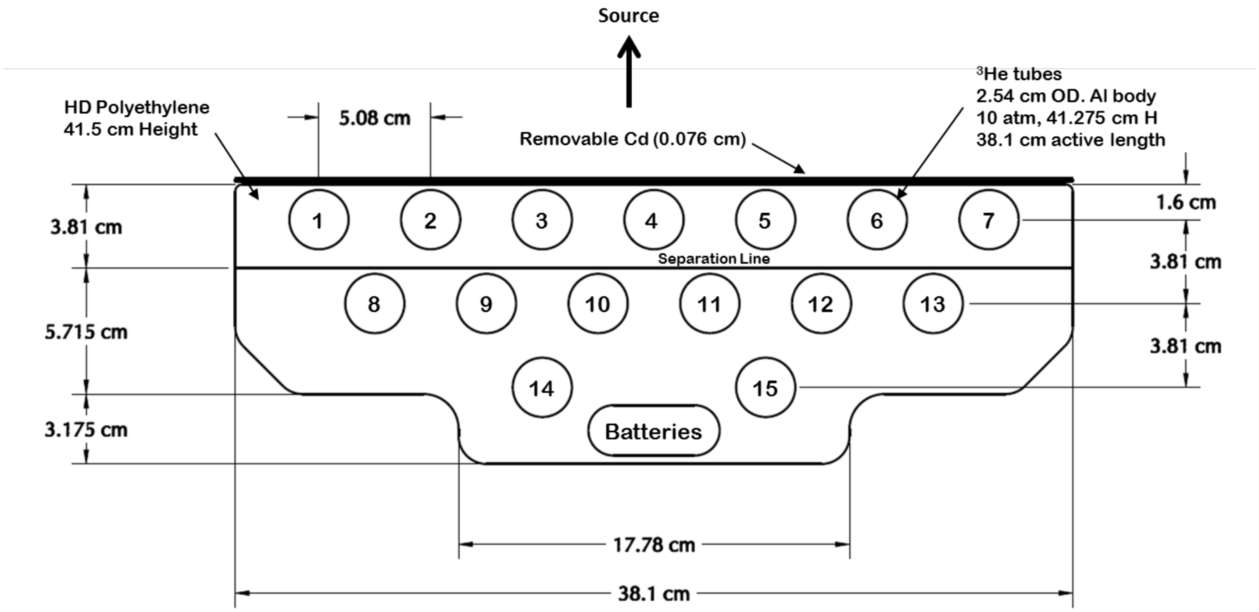



Figure 2. Layout of the $^3$He tubes in the MC-15.

The MC-15 has a removable front panel. This modularity allows for the MC-15 to be reconfigured in a variety of geometries.

The front panel is secured to the main body by four thumb screws as shown in Figure 3.


Figure 3. Locations of screws fastening the MC-15 front panel to the back panel.

When the front panel is removed from the main body, the front panel needs to be connected to the main body with the special cable as shown in Figure 4. The connectors are water-tight and labeled “Front Panel” and “Facing Out” for the back panel.

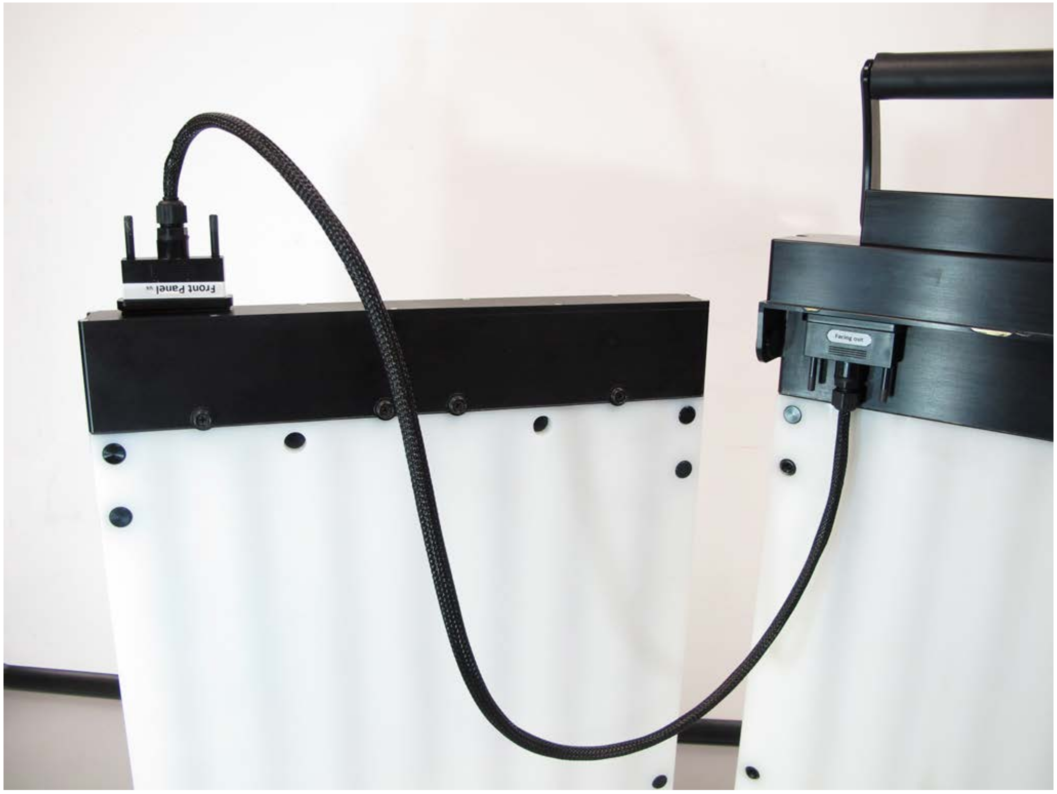



Figure 4. Special cable connecting the front panel (left) and the back panel (right).

During reassembly the front panel is aligned with the main body by a guide to insure the electrical connection is aligned as shown in Figure 5. Care must be taken to insure the electrical connection on the front body is on the same side as the electrical connection on the main body.

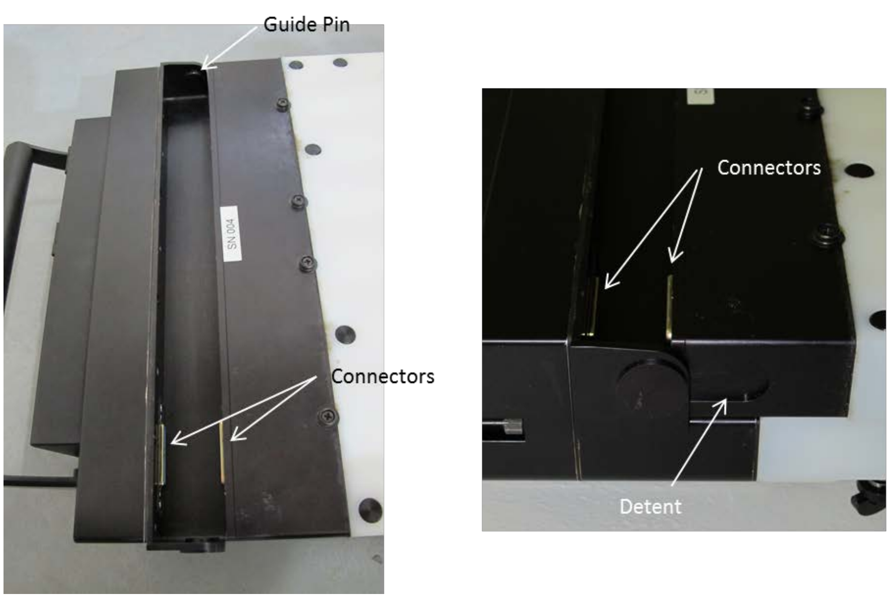



Figure 5. Front panel partially assembled with the main body (left in photos) and the back panel (bottom in photos)

Figure 6 shows a comparison of the MC-15 fully assembled and a configuration with the front panel separated.

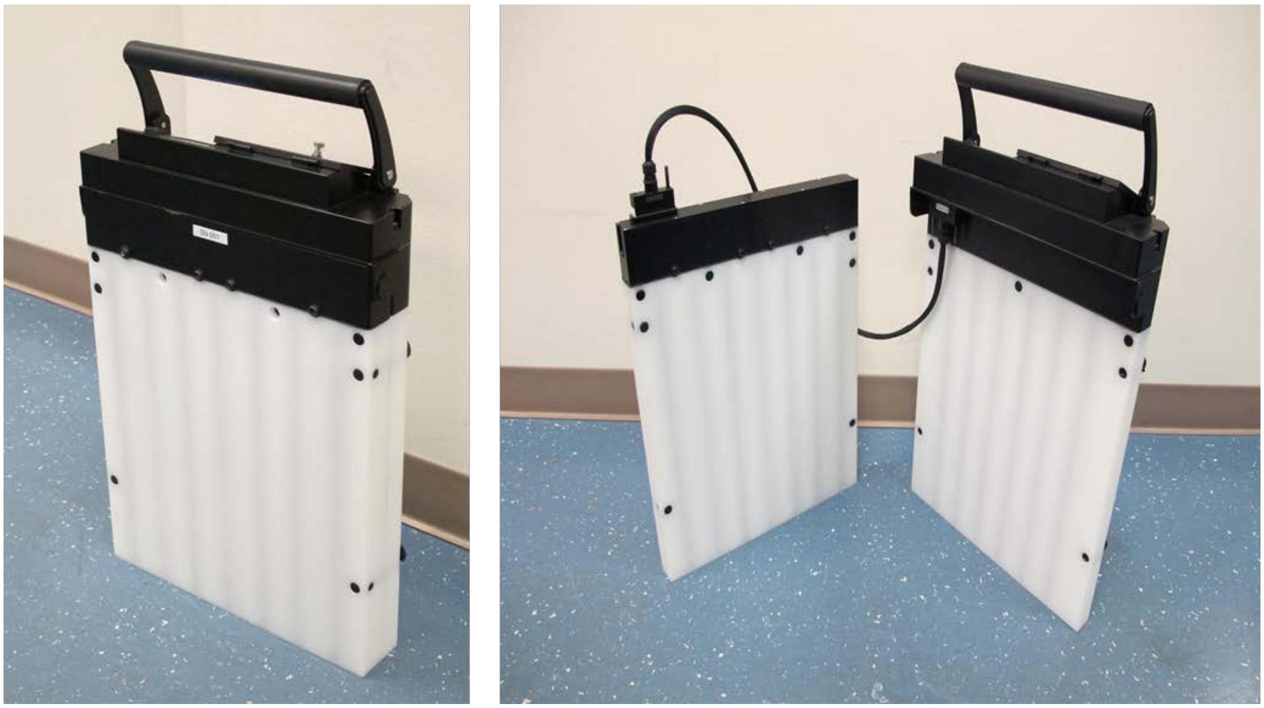


Figure 6. MC-15 with front panel attached (left); front panel separated (right).

### 2.3. Interface

The main operation of the MC-15 is performed through an LCD screen on the top of the main body.
All of the control electronics with firmware is contained in the detector head shown in Figure 7. The high resolution 3.5-inch color LCD touch screen has an extended temperature range and is readable in sunlight.

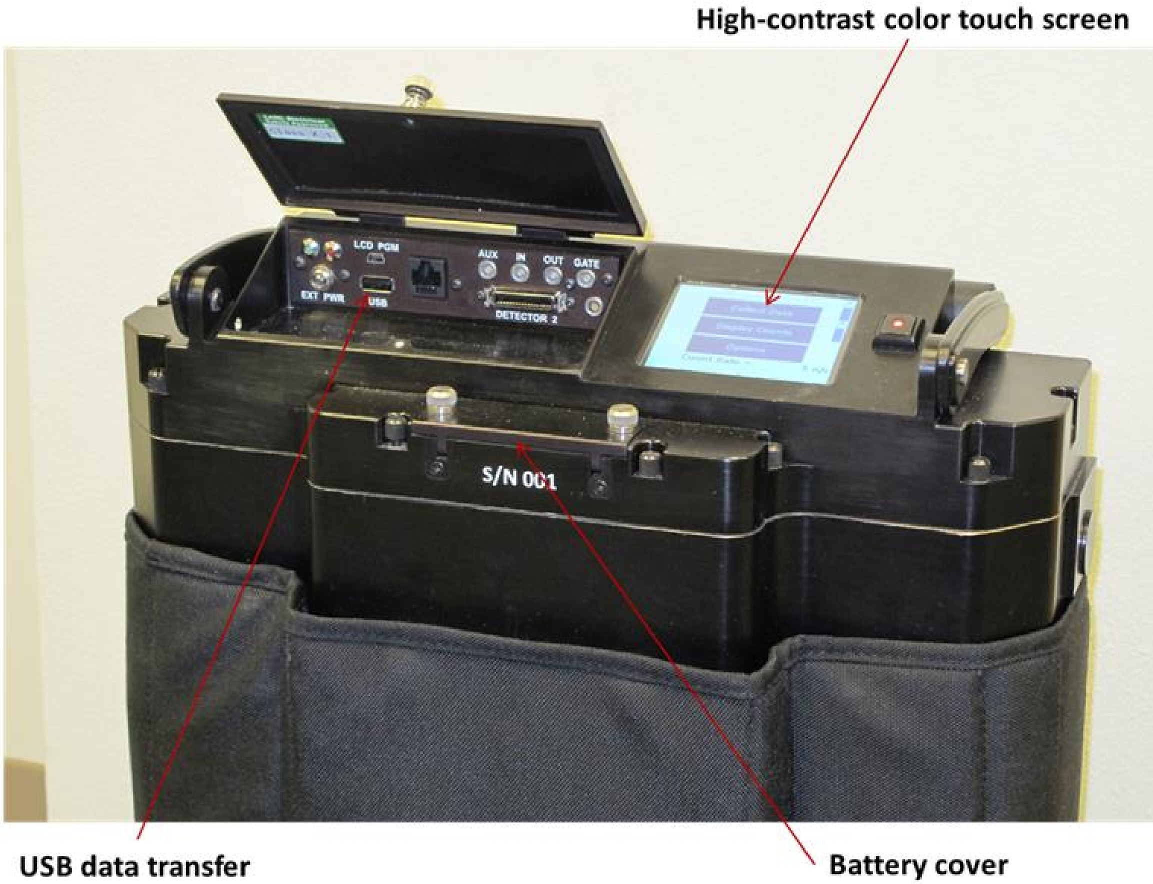



Figure 7. MC-15 detector head.

The electrical ports used for data transfer, interfacing with another detector or a computer, and charging are housed on the left side on top of the MC-15. These connections are protected from the environment by a cover with a gasket. These connections are not water proof, and it is recommended that the cover be closed when taking measurements in a wet environment. The interface connectors are shown in Figure 8.

The external power input (EXT PWR in Figure 7) is used to charge the batteries or to run the unit on AC power. The red LED is on when the battery is charging and goes off when the battery is fully charged. The green light is on whenever external power is connected. The top battery can be removed and charged separately with a charger (see Section 6). A stand-alone computer can be connected to the "LCD PGM" port to modify the display software for different applications. Data can be transferred to a USB device, such as a memory stick, via the "USB" port. The data can be read out in condensed mode (CMX) (See Appendix B), which creates Feynman histograms at a select number of gates, or in list mode

(LMX), which produces a larger file with time tagged data for each event (See Appendix A). The Ethernet port allows a stand-alone computer to be connected via a long cable for remote control and data download. This is essential for data collection in a high radiation environment. The “DETECTOR 2” allows a second MC-15 to be connected. For this configuration the data for all 30 channels, 15 for the primary detector and 15 from the secondary detector, are stored in the primary MC-15. The “IN” connector (pulse on >~ 2.0v, off <2.0v, max 6.5 v, minimum width ~50ns) allows an external detector to be counted in a 16th channel. Usually this detector is the SNAP, which provides an accurate measurement of the neutron source strength, but future measurement protocols may make this detector unnecessary. The “OUT” connector (pulse on >2v – 3.3v, off <2v, width 60ns) provides an output pulse whenever the MC-15 registers a count in any channel. Using the “IN” and “OUT” connectors allow several MC-15 instruments to be daisy chained together for greater detection efficiency. However, the individual channels are not recorded in list mode when more than two MC-15s are connected together in daisy chained mode. The “GATE” connector (pulse on >~2.3v, off <1.5v, max 6.5v, minimum width ~50ns) allows active interrogation techniques to veto data acquisition to minimize the size of data files.

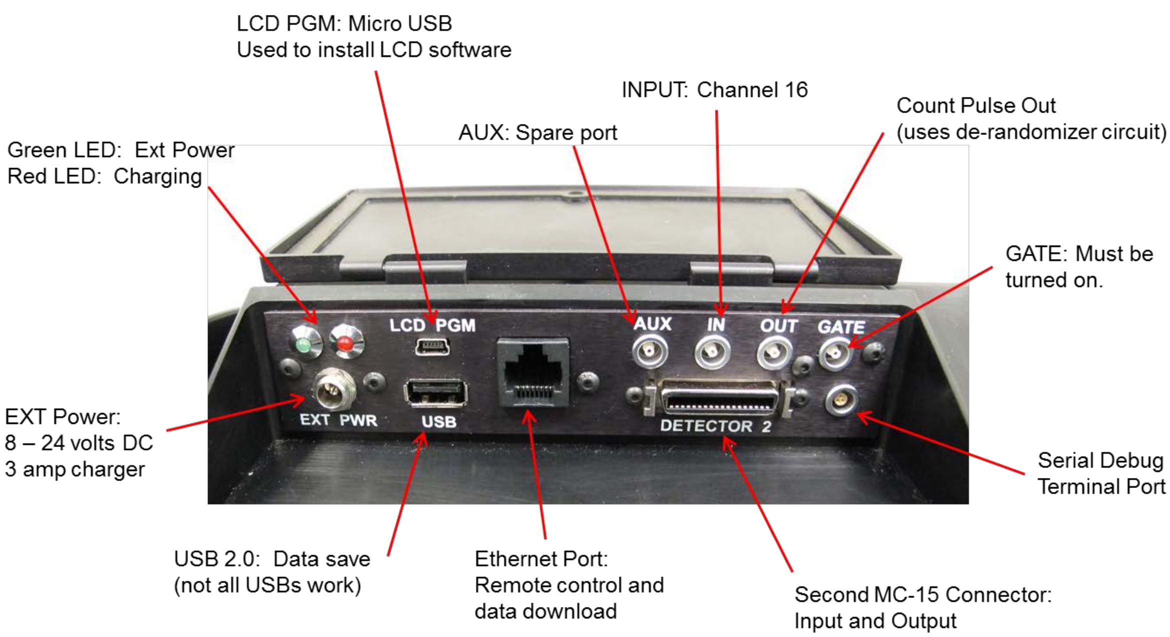



Figure 8. MC-15 I/O interface connectors.

### 2.4. Batteries

Power is provided by two lithium ion smart batteries like the one shown in Figure 9.  The locations of the two lithium ion batteries in the MC-15 are shown in Figures 10 and 11.  The top battery can be hot swapped.  A Phillips #1 screwdriver is need to access the bottom battery and is usually not swapped.  The charging level on each battery is indicated by bars on the display on the end of each battery as well as on some of the MC-15 screens. A single battery provides seven hours of run time and two batteries provide 14 hours.  The charging time is six hours.


Figure 9. Lithium ion smart battery.


Figure 10.  The top battery can be hot swapped.


Figure 11. Tools are required to access the bottom battery.

## 3. Deployment

The front of the MC-15 should be placed toward the source. In order to measure accurate absolute neutron outputs, the MC-15 should be placed as accurately as possible so that the center mark on the front face of the MC-15 is centered vertically and horizontally on the neutron hot spot and 30 cm from the center of the object of interest. Sections 3.1-3.2 give preferred configurations, but if these are not possible, the user should record the dimensions for future analysis. While data is being collected, personnel movement between the MC-15 and the object must be avoided. The internal memory and external USB memory stick should be erased at the start of a deployment exercise. The minimum data acquisition time is 5 minutes

### 3.1. Passive Measurement Setups

#### 3.1.1. Single MC-15

A simple passive configuration setup with one MC-15 is shown in Figure 12. The source output is assumed to be low enough so that the operator can be present at the MC-15. With the front of the MC-15 toward the source, the operator on the opposite side will be able to read the display. The souce is centered in front of the MC-15 and at the same height from the floor as the + on the MC-15. A distance of 30 cm from the front face of the MC-15 to the center of the source is recommended. Typically, a 5 minute count is sufficient for adequate statistics. However, a longer time might be necessary if the count rate is very low.

Figure 12. Setting up the MC-15 for a standard measurement.

The efficiency of the detection system can be increased by removing the front panel of tubes and placing it separately near the source as shown in Figure 13. Earlier in this manual, Figure 3 shows how the front panel is attached to the back panel, Figure 4 shows the special cable connecting the front and rear panels, and Figure 5 shows how the panels must be aligned to reassembly them.  Separating the panels increases the efficiency for low energy neutrons but reduces it for high energy neutrons.  The front panel must be connected to the rest of the MC-15 with the special cable provided (Figure 4).

Figure 13.  Two panel passive setup.

### 3.1.2. Two MC-15s

A simple passive configuration setup with two MC-15s is shown in Figure 14. The dimensions are the same as for the single MC-15. A distance of 30 cm from the front face of each MC-15 to the center of the source is recommended. The secondary MC-15 must be connected to the Detector 2 connector on the primary MC-15 using a special cable provided. One end of this cable is labeled “Primary” and the other is labeled “Secondary.” Connecting this cable will force the MC-15s to be primary and secondary to correspond to the cable labels. This configuration choice will be shown on the “Analysis Settings” screen (Figure 24 or 25) and the “Active Data Channels” screen (Figure 37).

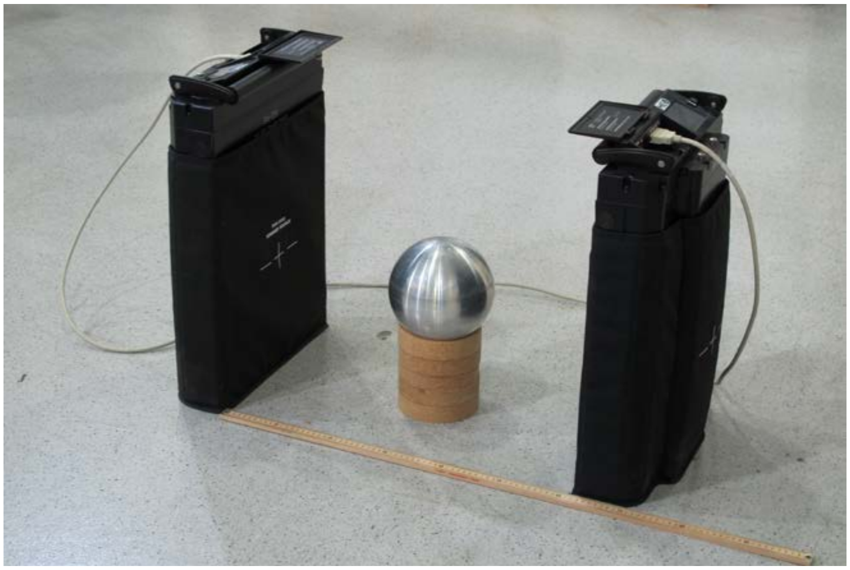


Figure 14. Setting for a standard measurement with two MC-15s.

Figure 15 shows a measurement in progress with a passive setup using two MC-15s with the front panels removed.

Figure 15. Example of a two MC-15 setup with the front panels removed to enhance the efficiency for low energy neutrons.

### 3.1.3. One MC-15 with SNAP

**A** SNAP (Shielded Neutron Analysis Probe), which should provide a more accurate value of the neutron source output than the MC-15, can be added to the setup. The SNAP should be located directly opposite the MC-15 at 100 cm as shown in Figure 16. The SNAP center reference point is indicated by a + on the top of the SNAP. The recommend distance for the MC-15 is still 30 cm. The SNAP should be connected to the "IN" input of the MC-15 with a LEMO cable, and recording of this input is enabled by default but can be confirmed by checking that the Ext. Input box in the Active Data Channels screen (Figure 37) is checked.

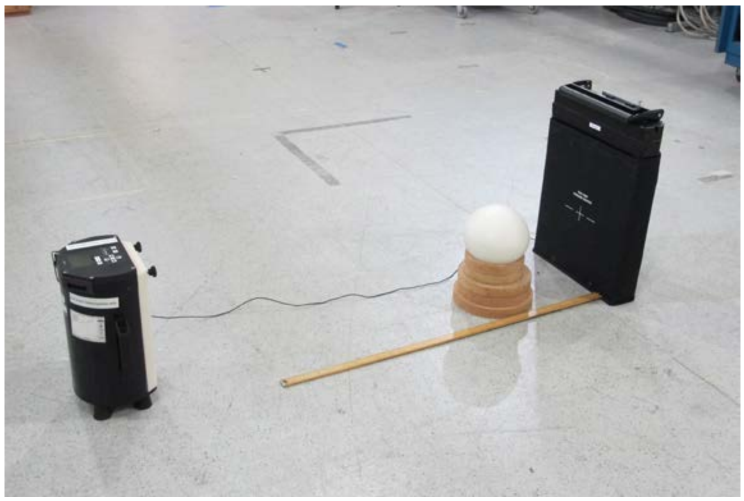


Figure 16. Simple passive setup with the SNAP (left) and MC-15 (right).

### 3.1.4. Two MC-15s with SNAP

The SNAP can also be used with two MC-15s as shown in Figure 17. The recommended distances are 30 cm for the MC-15s and 100 cm for the SNAP. Obviously, the detectors must be arranged so that an MC-15 is not between the source and the SNAP. Also, the reflection of neutrons by the MC-15s to the SNAP should be minimized by placing the MC-15s to the side as shown in Figure 17 instead of behind the test object and opposite the SNAP.

Figure 17. Simple setup with two MC-15s and the SNAP

### 3.2. Active Measurement Setups

As with the passive measurement setup, many detector configurations are possible. The main difference is that a DT neutron generator is placed close to the object of interest. The neutron generator output point should be at the same height as the heights of the object being interrogated and the MC-15(s). The generator must be placed so as not to attenuate the delayed neutrons traveling toward the detector(s). For radiation safety, the control of the DT generator must be accomplished remotely. The MC-15 could also be controlled remotely, or the operator could start the MC-15 and retreat to a safe distance before starting the DT generator remotely. More details about active measurements, including details about the operation of the generator, are available in reference [1].

#### 3.2.1. Active with One MC-15

Figure 18 shows a simple active configuration setup that includes a DT neutron generator, MC-15, and SNAP. The SNAP detector is connected to the IN port, which is recorded in channel 16. The MC-15 may be controlled by a remote laptop via a cable connected to the Ethernet connector. A signal from the DT generator is connected to the GATE input on the MC-15 to gate off the data collection during the interrogating neutron pulse in order to reduce the size of the data files. The Veto Active, Veto Duration, and Veto True State are selected in the Setup screen (Figure 32).

Figure 18. Simple active configuration setup.

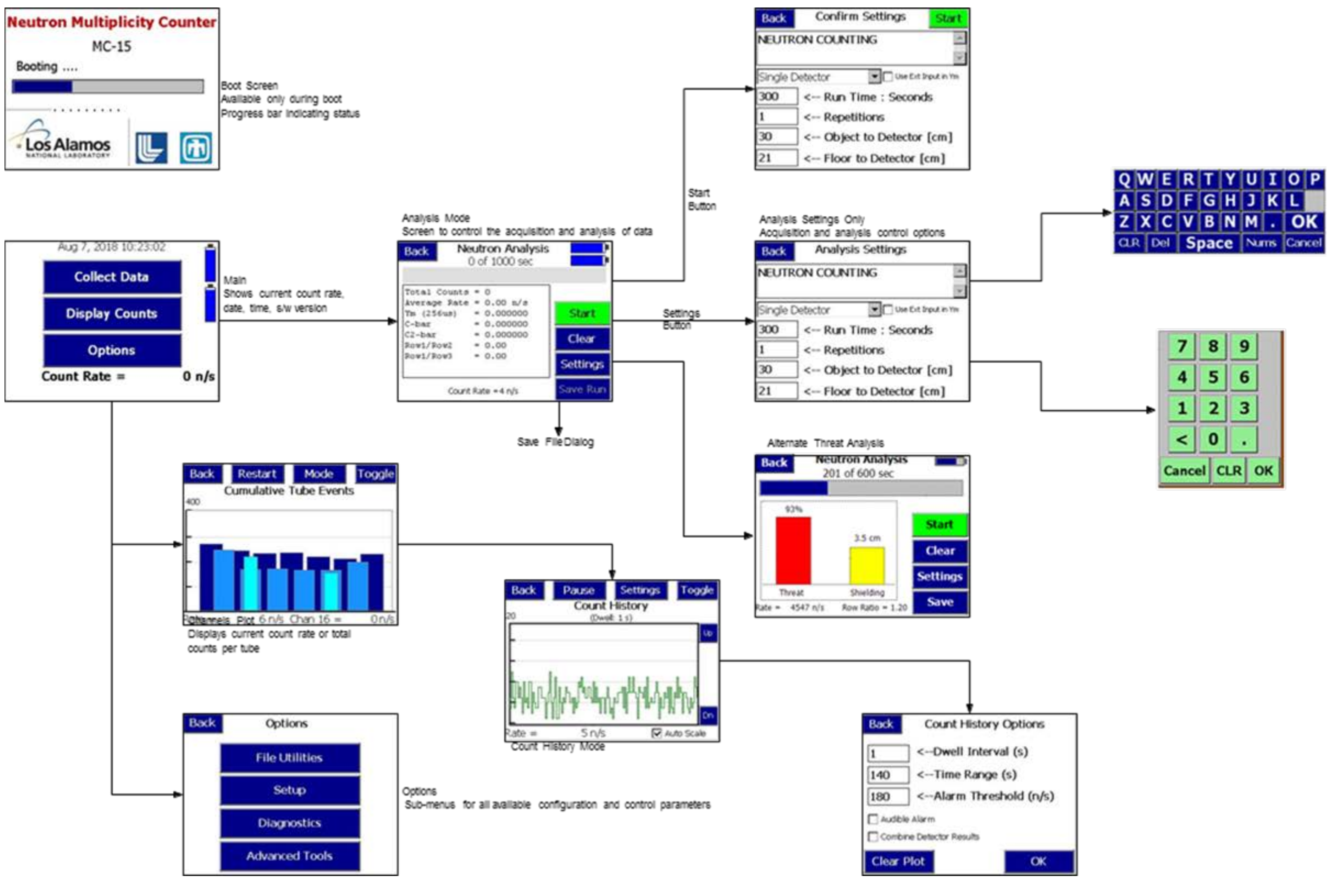
### 3.2.2. Active with Two MC-15s

Figure 19 shows a simple active configuration setup that includes a DT neutron generator, two MC-15s, and a SNAP. In this setup, the MC-15s are at 50 cm but the SNAP is still at 100 cm.


Figure 19. Active setup with two MC-15s and the SNAP.

### 4. MC-15 Control

All of the MC-15 operations are controlled either on the instrument itself using the high-resolution color touch screen LCD or remotely by a laptop connected via an Ethernet cable. Figure 17 is a flow chart of the commands. The following sections discuss the various screens.



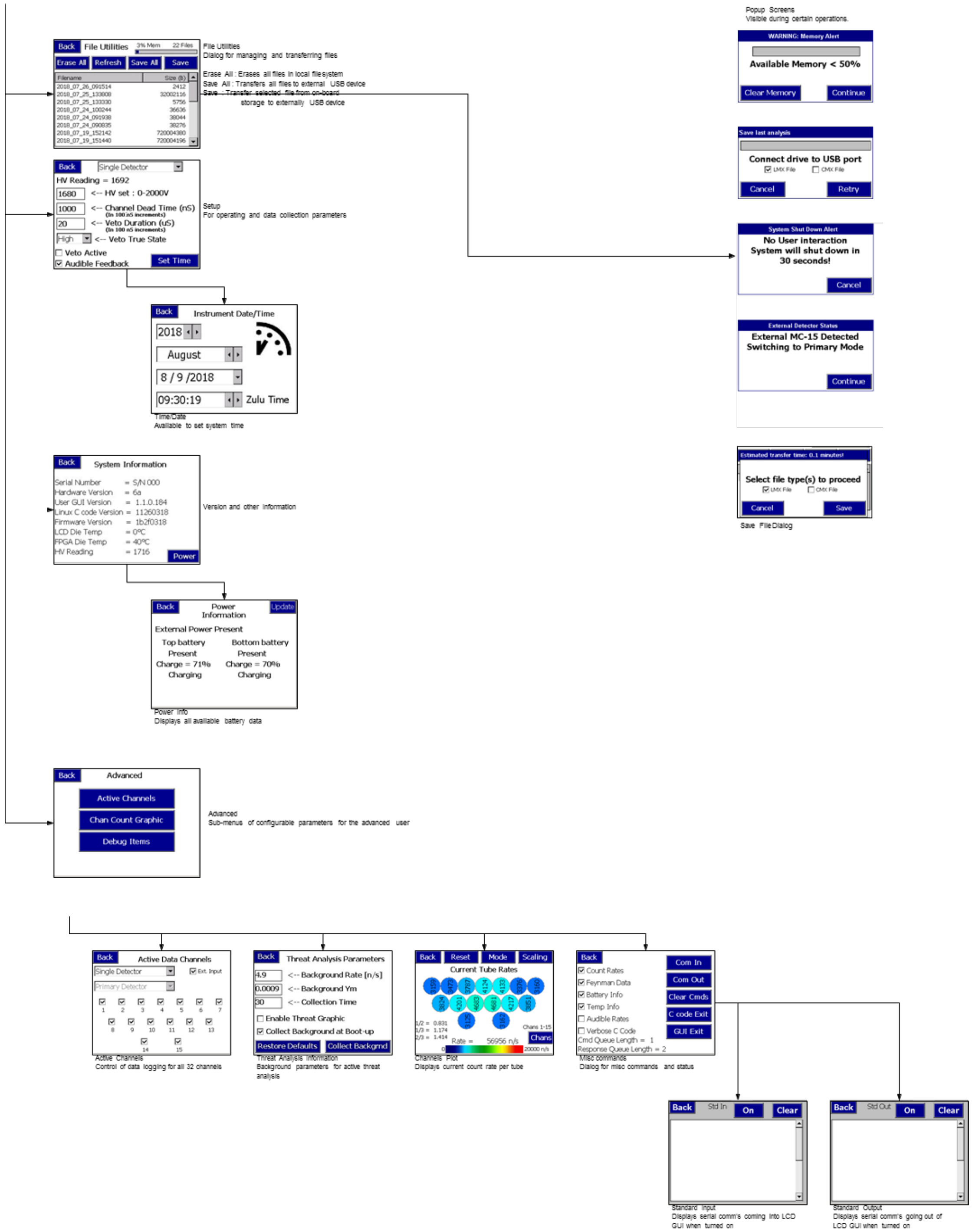


Figure 20. Flow chart of the MC-15 control screens on two pages.

### *Starting Operation*

When the MC-15 is powered on, the system immediately begins booting up. First the screen displays the boot screen shown in Figure 21 with a progress bar indicating the status. The line below the status bar reports the sequence of operations: reading configuration, building user interface, setting parameters, building file list, and cleaning up. This screen is only displayed during boot up. Possible warning pop-up messages are “Memory Low (< 5%)” and “Battery Low (<10%)”. When the boot up is finished, the Main screen shown in Figure 22 is displayed. The boot up typically takes 20 seconds.

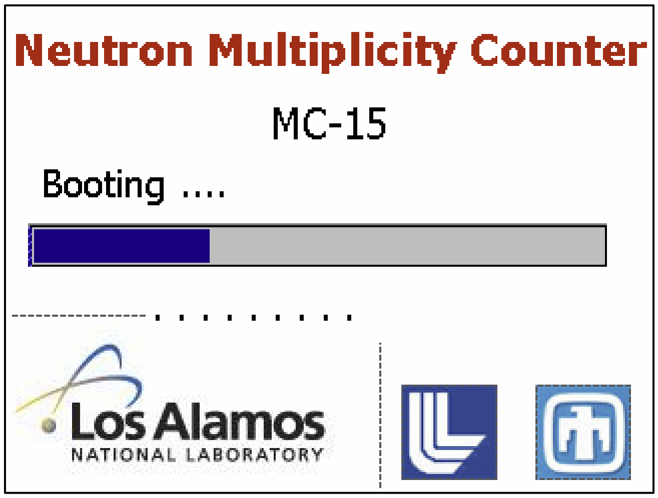



Figure 21. Boot up screen.

*Main Screen*

The main screen (Figure 22) shows the date, time, and neutron count rate in the 15 $^{3}$He tubes in the MC-15. The secondary rate is the rate in a second MC-15 if a second MC-15 is connected to the primary MC-15. The time and rates are updated once per second. The bars in the upper right corner indicate the charging level of the upper and lower lithium batteries. The battery color is blue if normal, green if charging, and red if low. Three links are provided that navigate to their respective interface elements. This screen will power off if there is no activity in 15 minutes.

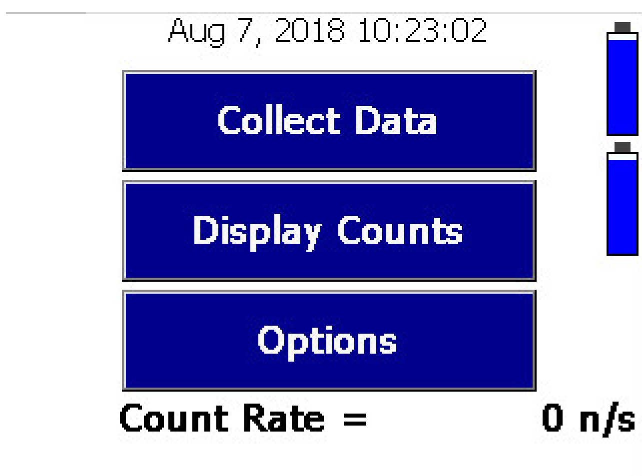



Figure 22. Main navigation screen.

### *Neutron Analysis Mode*

If Collect Data is selected in the Main screen (Figure 22), the Neutron Analysis screen shown in Figure 23 is displayed. This screen gives the time completed and total run time, the name of the run when completed, the total counts, and the average rate. Ym is the reduced Feynman Variance with a bin width of 256 µs. C-bar and C2-bar are the moments in the Feynman Variance analysis.

Row1/Row2 is the ratio of the count rates in four (2+3+5+6) of the front seven detectors to four (9+10+11+12) of the middle six detectors. Similarly, Row1/Row3 is the ratio of the count rates in the same four of the front seven detectors to the back two detectors. These ratios give some indication of the energy of the neutrons. When this screen is first accessed after the boot up, all of the values in the box will be zero. The count rate at the bottom is updated every second. The battery charging levels are displayed in the upper right corner. This screen provides links to other screens and functions: Start, Clear, Settings, and Save Run.

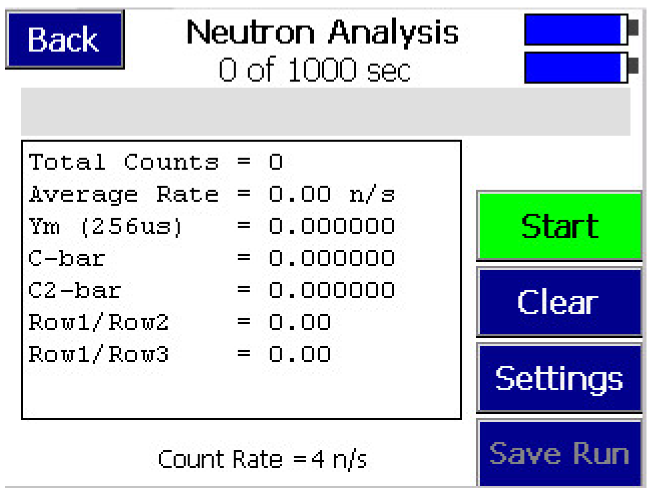



Figure 23. Neutron Analysis screen.

### *Analysis Settings with Start Option*

If Start is selected in the Neutron Analysis screen (Figure 23), the Analysis Settings with Start Option screen shown in Figure 24 is displayed. Touching the Run Description panel opens a key pad so that a description can be entered. The pull down menu in the Analysis Settings panel allows the selection of either a single detector or two detectors. Checking the box labeled “Use Ext Input in Ym” enables the use of the channel 16 counts, received via the IN input, in the calculation of Ym. If there are two MC-15s, channel 32 counts are also used. Touching the Run Time: Seconds, Repetitions, Distance to Object [cm], or Distance to Floor [cm] box opens a numeric keypad so that the value can be changed. The maximum number of repetitions is limited by the number of files available in internal storage (200 max). A run can be started by touching Start. The maximum data file size is 2GB and the maximum sample count is 260 million. When the sample count exceeds this value, a message will appear on the LCD telling the operator that the assay has been cancelled, and the EndOFAssayStatus in the lmx header will show “Cancelled by file size limit.” (See Appendix A)

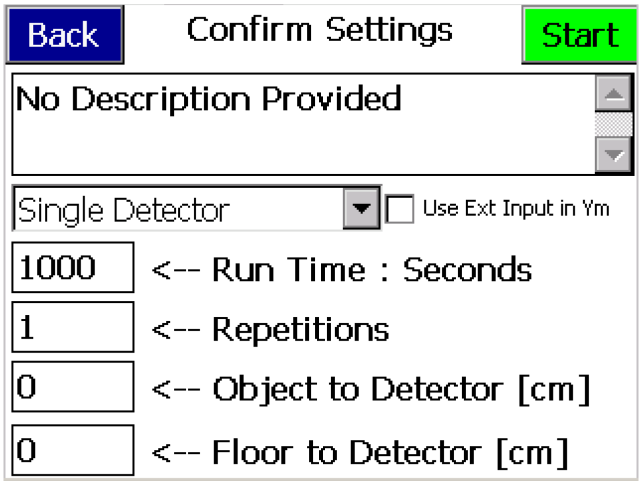



Figure 24. Analysis Settings with Start Option screen

### *Clear*

If Clear is selected in the Neutron Analysis screen (Figure 23), the elapsed time is set to 0, the run label changes to blank, and all of the values in the box are set to 0. The current rate will continue to update every second.

### *Settings*

If Settings is selected in the Neutron Analysis screen (Figure 23), the Analysis Settings Only screen shown in Figure 25 is displayed. Touching the Run Description panel opens a key pad so that a description can be entered. The pull down menu in the next panel allows the selection of either a single detector or two MC-15 detectors. Checking the box labeled “Use Ext Input in Ym” enables the use of the channel 16 counts, received via the IN input, in the calculation of Ym. If there are two MC-15s, channel 32 counts are also used. Touching the Run Time : Seconds, Repetitions, Distance to Object [cm], or Distance to Floor [cm] box opens a numeric keypad so that the value can be changed. The only link from this screen is Back to the Neutron Analysis screen (Figure 23).

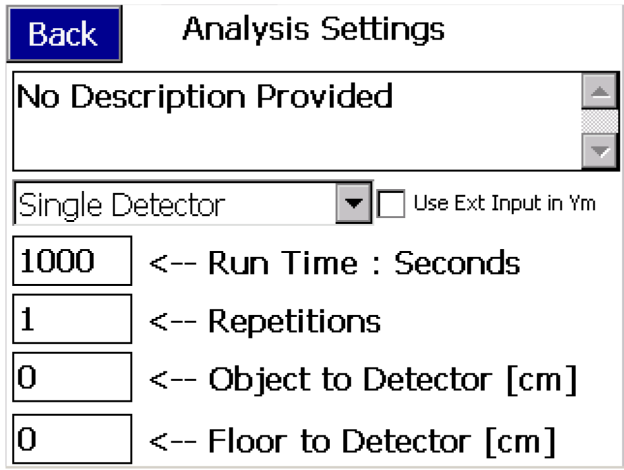



Figure 25. Analysis Settings Only screen.

### *Save Run*

If Save Run is selected in the Neutron Analysis screen (Figure 23), the Save File Confirmation screen shown in Figure 26 is displayed. The Save Run button is only enabled once an analysis has been collected. Select the file types to proceed, either LMX, CMX or both. Touching Save will enable saving to the USB port if a USB storage device is connected to the USB port. The operation can be canceled by touching Cancel and the system returns to the Neutron Analysis screen (Figure 23).

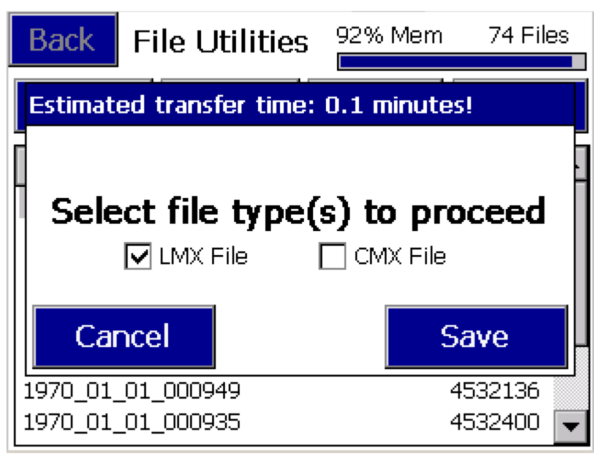



Figure 26. Save File Confirmation screen.

### *Cumulative Tube Events*

If Display Counts is selected in the Main screen (Figure 22), the Cumulative Tube Events screen shown in Figure 27 is displayed. The 15 bars give the total counts per tube or the current count rate. The seven dark blue bars are for the tubes closest to the front surface, the light six light blue bars are for tubes in the next row, and the two aqua bars are for the tubes in the rear. The total count rates in tubes 1-15 and the count rate in channel 16 are displayed at the bottom. Initially the total counts per tube are displayed, but this can be switched to the 1 second count rates as shown in Figure 27 by touching Mode.

The displayed values can be reset to zero by touching Restart. If Toggle is touched, the Count History screen as shown in Figure 28 is displayed.

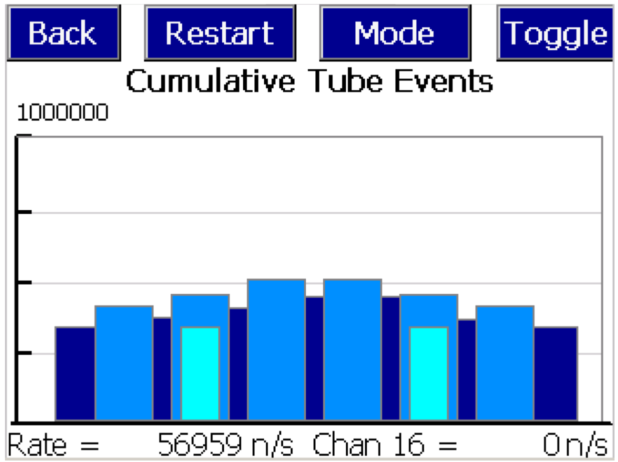



Figure 27. Cumulative Tube Events screen.

### *Count History*

The Count History screen shown in Figure 28 is selected by touching Toggle in the Cumulative Tube Events screen (Figure 27). The sum of the count rates in all tubes is displayed. If there is only one MC-15, then only one plot for channels 1-16 is shown. If there is a second MC-15 connected, then a second plot for channels 17-32 is shown. However, if the Combine Detector Results box is checked in the Count History Options screen (Figure 29), then only the sum of 1-16 and 17-32 is plotted. The rate at the bottom in Figure 28 is the sum of channels 1-16 if there is only one MC-15 connected or the sum of channels 1-32 if there are two MC-15s connected. The vertical scale will automatically scale if the Auto Scale box is checked or the scale can be manually changed with the Up or Dn buttons. Pause stops the updating of the display. If Back is touched, the Main screen is again displayed (Figure 22). If Toggle is touched, the Cumulative Tube Events screen is again displayed (Figure 27). If Settings is touched, the Count History Options as shown in Figure 29 is displayed.

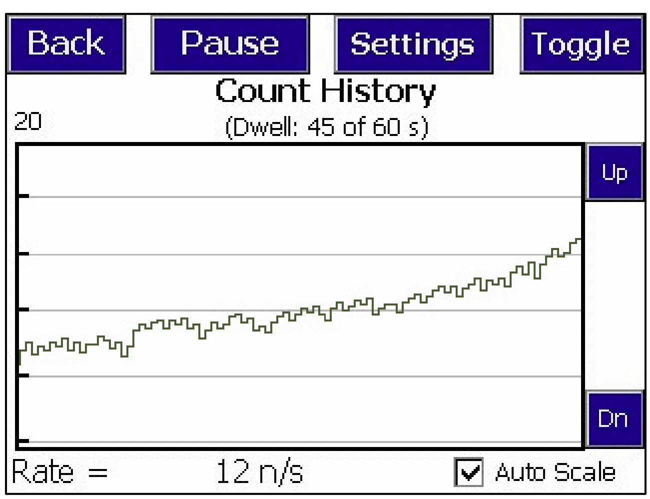



Figure 28. Count History screen.

### *Count History Options*

The Count History Options screen shown in Figure 29 is selected by touching Settings in the Count History screen (Figure 28). Touching the Dwell Interval (s), Time Range (s), or Alarm Threshold (n/s) will bring up a numeric key pad for changing the values. If the Combine Detector Results box is checked, the sum of 1-16 and 17-32 is plotted in the Count History screen (Figure 28) rather than separate plots for each MC-15. Touching Clear Plot will clear the Count History. If Back or OK is touched, the Count History screen (Figure 28) is again displayed.

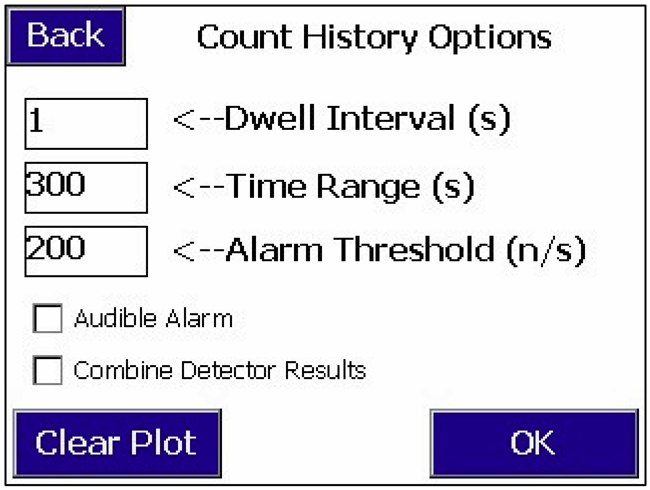



Figure 29. Count History Options screen.

### *Options*

If Options is selected in the Main screen (Figure 22), then the Options screen is displayed as shown in Figure 30. Four links are provided to navigate to their respective screens.

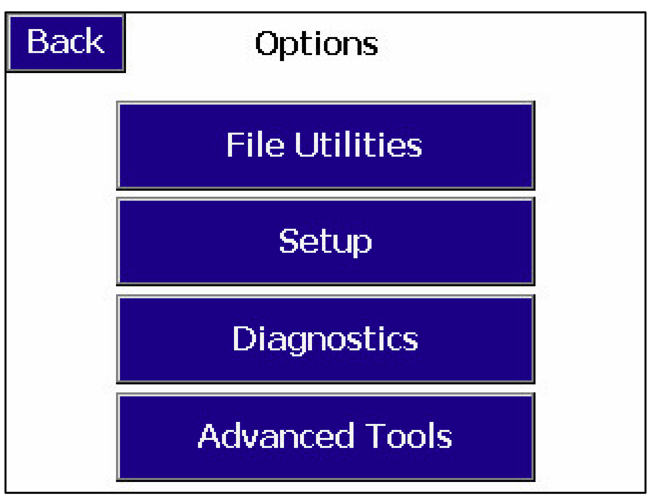



Figure 30. Options screen.

*File Utilities*

If File Utilities is selected in the Options screen (Figure 30), then the File Utilities screen shown in Figure 31 is displayed. All of the data files stored in the internal memory are listed. To save a single file to an external USB memory stick, highlight it, then touch Save. The Save File Confirmation screen shown in Figure 26 will be displayed. The internal memory capacity is 128 GB and the maximum number of files is 200. To save all of the files, touch Save All. The screen shown in Figure 26 will be displayed. To erase all the files in the local files system, touch Erase All. Touching Back returns to the Options screen (Figure 30)

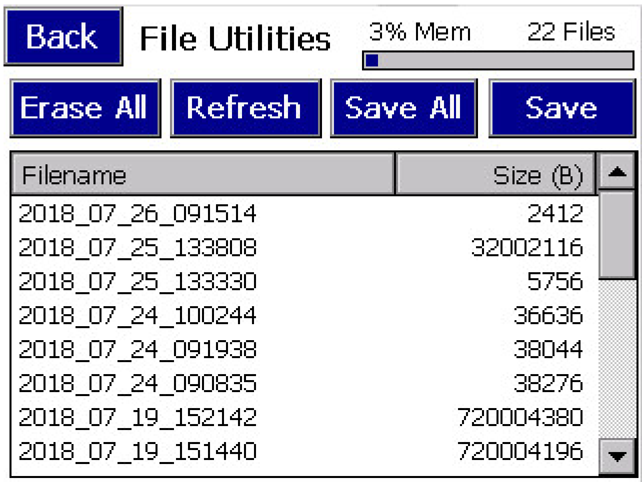



Figure 31. Files Utilities screen.

*Setup*

If Setup is selected in the Options screen (Figure 30), then the Setup screen shown in Figure 32 is displayed. The top pull down menu allows the system to be configured for one or two MC-15s. The HV Reading is updated every second. The next three boxes allow the HV, Channel Dead Time, and Veto Duration to be entered. The bottom pull down menu allows the choice of “low” or “high” for the veto gate input. Check the Veto Active box to enable the veto gate. Audible Feedback can be enabled by checking the corresponding box. Audible Feedback controls the beeping at the end of an analysis. To set the date and time touch the Set Time to display the Instrument Date/Time screen shown in Figure 33. Touching Back returns to the Options screen (Figure 30).

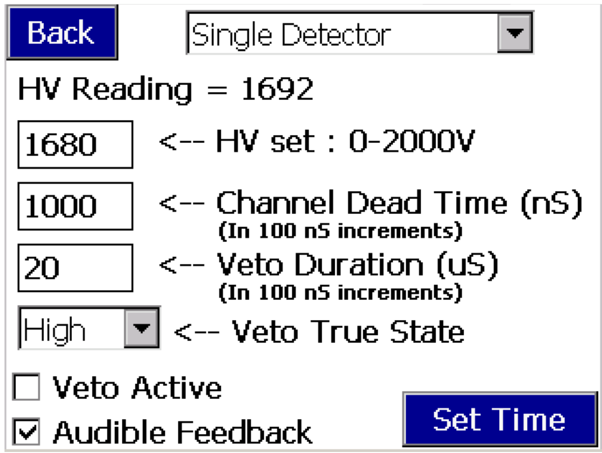



Figure 32. Setup screen.

### *Instrument Date/Time*

The Instrument Date/Time screen in Figure 33 is accessed by touching Set Time in the Setup screen (Figure 32). The four boxes allow the Zulu date and time to be entered. Touching Back returns to the Options screen (Figure 30).

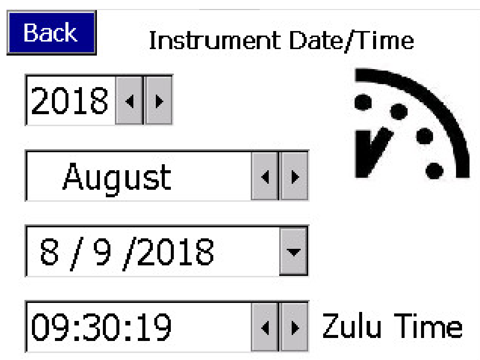



Figure 33. Instrument Date/Time screen.

### *System Information*

If Diagnostics is selected in the Options screen (Figure 30), then the System Information screen shown in Figure 34 is displayed. Information about the hardware and software/firmware versions is provided. The temperatures and HV Reading are updated every second. Touching Power opens the Power Information screen shown in Figure 35. Touching Back returns to the Options screen (Figure 30).

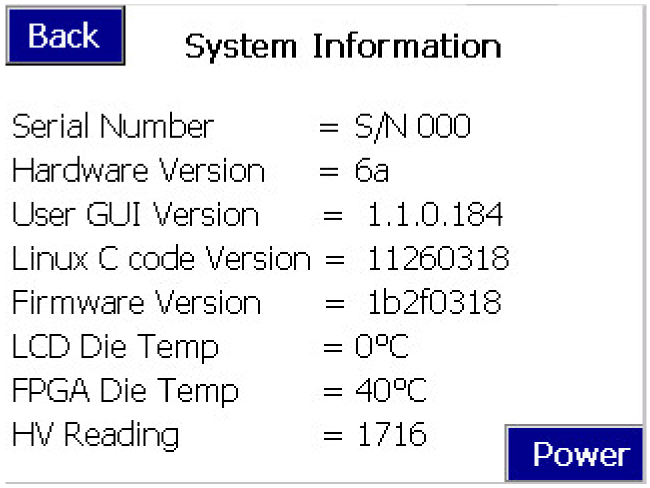



Figure 34. System Information for diagnostics.

### *Power Information*

The Power Information screen (Figure 35) is accessed by touching Power in the System Information screen (Figure 34). The status of the two batteries is shown. Touching Back returns to the System Information screen (Figure 34).

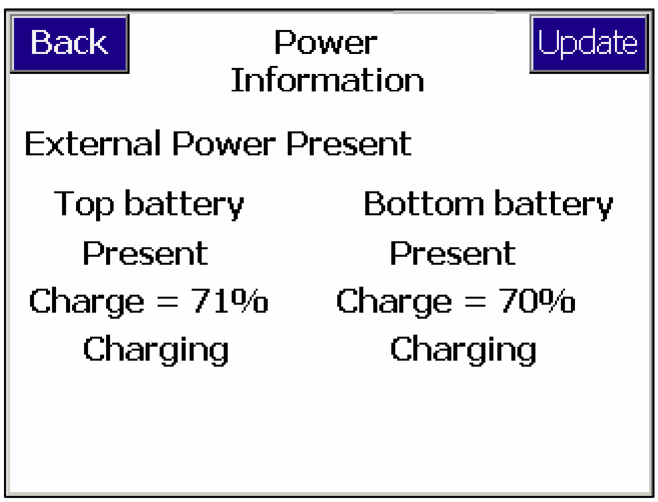



Figure 35. Power Information screen.

### *Advanced Tools*

If Advanced Tools is selected in the Options screen (Figure 30), then the Advanced screen shown in Figure 36 is displayed. Three links are provided to navigate to their respective screens.

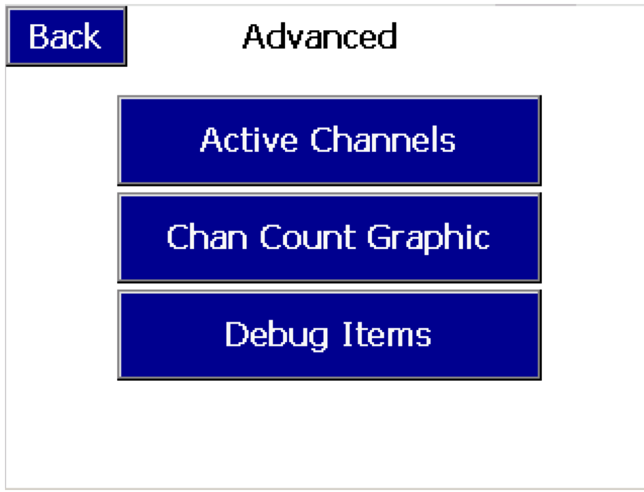



Figure 36. Advanced screen.

*Advanced Channels*

If Active Channels is selected in the Advanced screen (Figure 36), then the Active Data Channels screen shown in Figure 37 is displayed. The top pull down menu allows the selection of the system configuration: a single detector or two detectors. The second pull down menu allows the user to control the active channels recorded on either the primary or secondary detector. This menu is only enabled if the top menu selection is “2 Detector Primary”. If the Ext. Input box is checked when “Primary Detector” is displayed in the second pull-down menu, then counts received at the IN input of the primary MC-15 are recorded in channel 16. Similarly, if the Ext. Input box is checked when “Multiple Detectors” is displayed in the second pull-down menu, then counts received at the IN input of the secondary MC-15 are recorded in channel 32. Whether these counts are used in the Ym calculation is determined by the “Use Ext Input in Ym” box on the Analysis Setup Screens (Figures 24 and 25). Boxes 1 -15 can be used to select which tubes are recorded. Similarly, if “Multiple Detectors” is displayed, boxes 17-31 can be used to select which of these tubes are recorded. Touching Back returns to the Advanced screen (Figure 36).

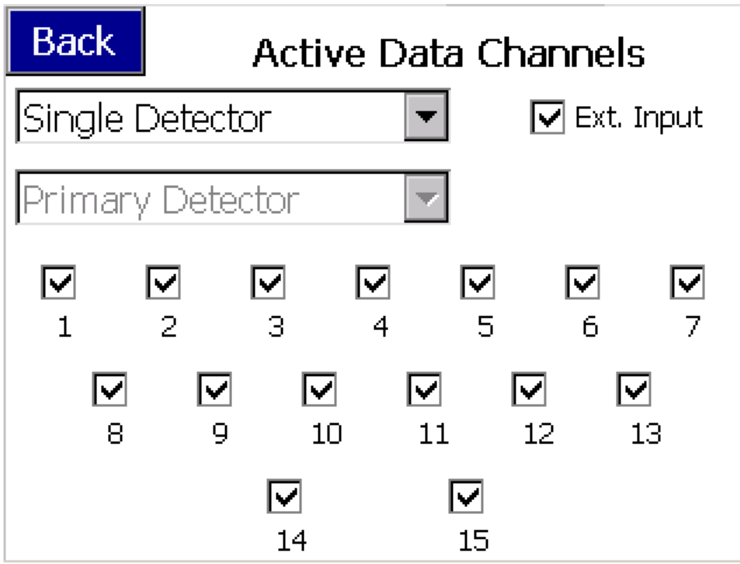



Figure 37.  Active Data Channels screen.

### *Current Tube Rates*

If Chan Count Graphic is selected in the Advanced screen (Figure 36), then the Current Tube Rates screen shown in Figure 38 is displayed.  The arrangement of the circles presents the location of the tubes in the MC-15.  The top seven are for the row of tubes closest to the front surface, the next six are for tubes in the next row, and the bottom two are for the tubes in the rear row.   The current tube rate in each tube are color coded with the scale at the bottom. The maximum of the color scale is set to 20000 n/s.  Touching Scaling sets the color maximum to the maximum tube rate as shown in Figure 39.  The ratios of the rates in the rows (lower left) and the total rate in all of the tubes (bottom) are shown.  All of the values are updated every second. Touching Reset zeros all of the values.  Touching Mode changes to the Cumulative Tube Events display shown in Figures 40 and 41.  Touching Chans switches to a display of channels 17-31, which are the values for the 15 tubes in a second detector, if present.  Touching Back returns to the Advanced screen (Figure 36).

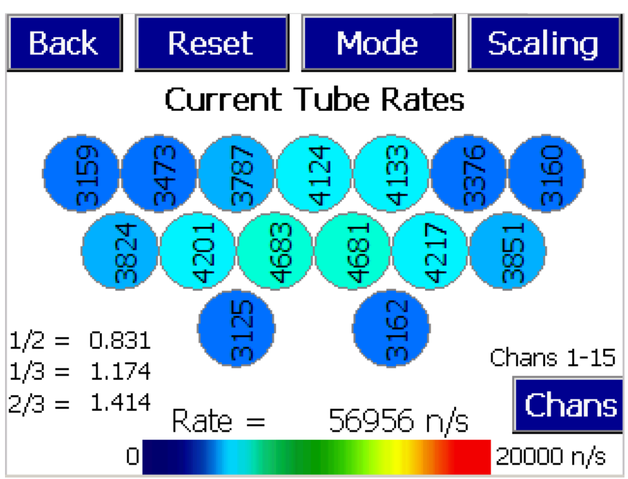



Figure 38.  Current Tube Rates screen.

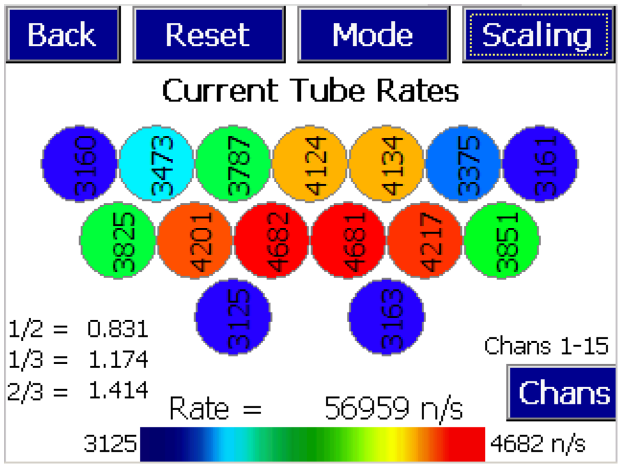



Figure 39. Color-scaled Current Tube Rates screen.

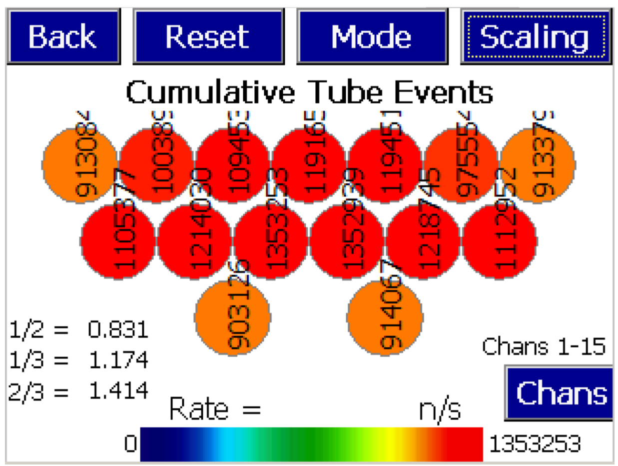



Figure 40. Cumulative Tube Events.

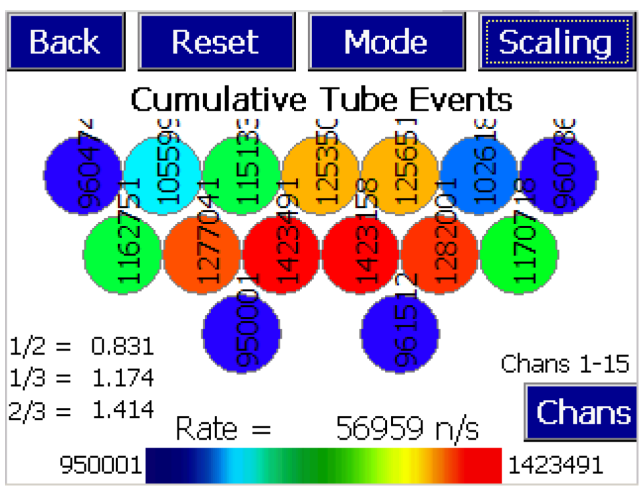



Figure 41. Color-scaled Cumulative Tube Events.

### *Miscellaneous Command*

If Debug Items is selected in the Advanced screen (Figure 36), the Miscellaneous Command screen shown in Figure 42 is displayed. If “Count Rates,” “Feynman Data,” “Battery Info,” or “Temp Info” are unchecked, the information is not sent to the user interface. “Audible Rates” controls beeping with a frequency corresponding to the count rate. Touching Com In brings up the Standard Input (COM1) screen shown in Figure 43. Touching Com Out brings up the Standard Output (COM1) screen shown in Figure 44. These COM screens show the dialog being transmitted between the user Ethernet interface and the embedded computer within the MC-15. They are generally only used for debug purposes. Touching Back returns to the Advanced screen (Figure 36).

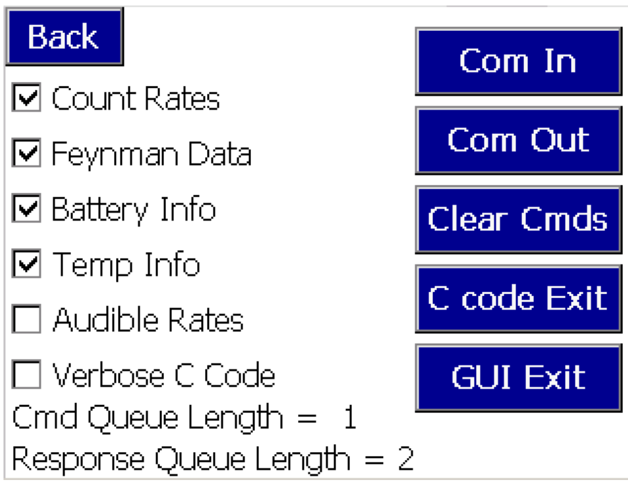



Figure 42. Miscellaneous Command screen

### *Standard Input*

If Com In is selected in the Miscellaneous Command screen (Figure 42), the Standard Input (Com1) screen shown in Figure 43 is displayed. When turned on by touching On, it shows the commands being received by the embedded system via the user Ethernet interface. Touching Clear, clears the display box. Touching Back returns to the Miscellaneous Command screen.

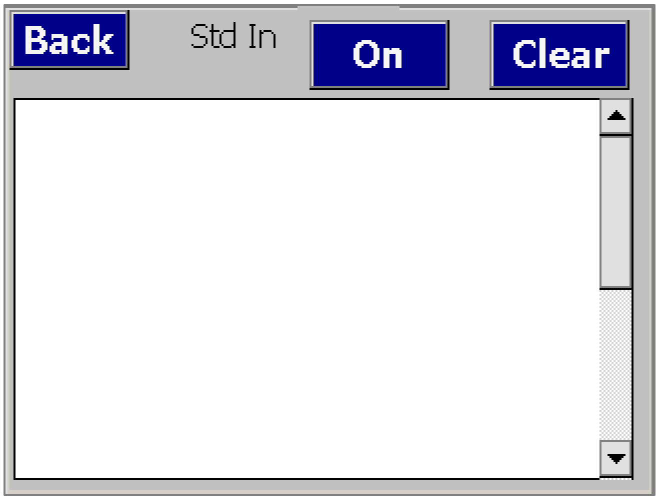



Figure 43. Standard Input (COM1) screen.

### *Standard Output*

If Com Out is selected in the Miscellaneous Command screen (Figure 42), the Standard Output (Com1) screen shown in Figure 44 is displayed. When turned on by touching On, it shows the commands being sent by the embedded system via the user Ethernet interface. Touching Clear, clears the display box. Touching Back returns to the Miscellaneous Command screen (Figure 42).

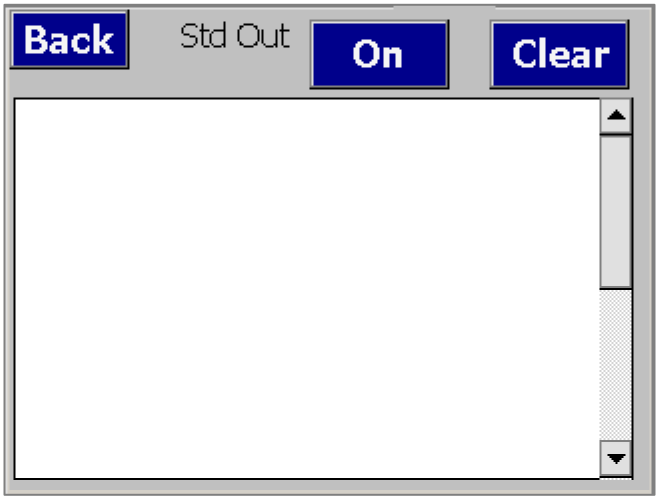



Figure 44. Standard Output (COM1) screen.

## 5. Shipping Case

The MC-15 and all essential accessories can be packed in one shipping case as shown in Figures 45 and 46.

Figure 45. MC-15 and shipping case.

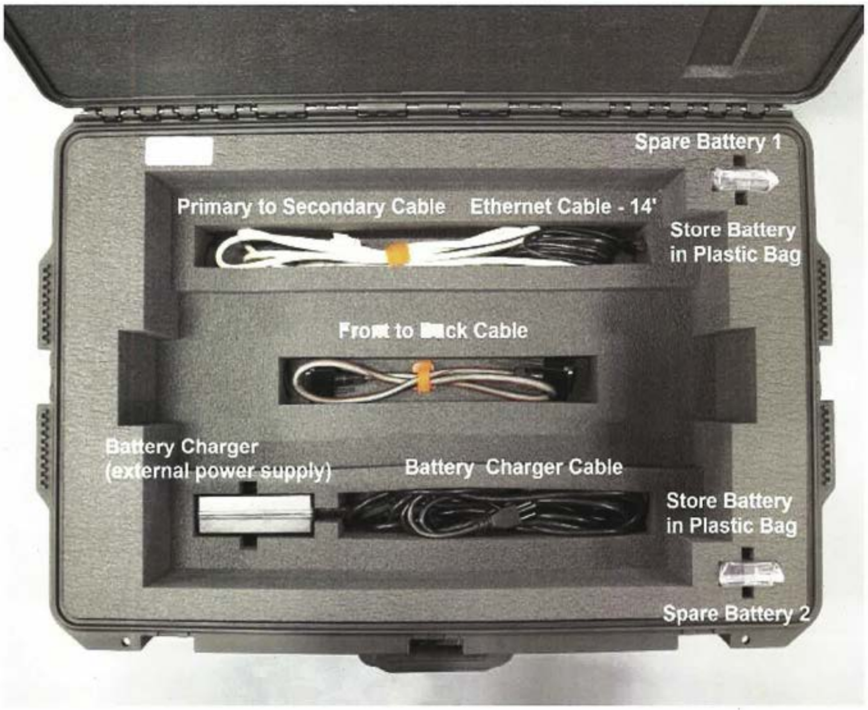



Figure 46. Essential accessory items in the MC-15 shipping case.

## 6. Lithium Ion Smart Battery

The NI2040ED Smart Battery shown in Figure 47 includes a rechargeable Lithium Ion battery and a Battery Management Module. The battery consists of (9) Lithium Ion rechargeable cells of 18650 size, assembled in a 3 series / 3 parallel (3S 3P) configuration. Each cell has an average voltage of 3.6V and a typical capacity of 2.9Ah giving a battery pack of 10.8V and 8.7Ah typical. The battery is capable of communicating with the host or the charger through the System Management Bus (SMBus). The battery is fully SMBus and SBDS Revision 1.1 compliant. Protection is provided for over-charge, over discharge and short circuit. For redundancy, passive safety devices have been integrated into the pack to protect against over-current and over-temperature, and secondary over-voltage has been implemented with a logic-fuse and controller.


Figure 47. Lithium ion smart battery.

Table 1. Ni2040 Smart Li Ion Battery Specification Summary

| | | |
|---|---|---|
| Part Number: | Ni2040ED29 | 2.9Ah cells, Extreme discharge |
| Chemistry / Cell Array | Nine Lithium Ion 18650 cells in a 3S3P array | |
| Capacity / Energy | 8.7Ah / 94Wh | |
| Voltage | $V_{max}$=12.6V $V_{nom}$=10.8 V $V_{cutoff}$=7.2V | |
| Equivalent Lithium Content | 7.83g | |
| Maximum continuous discharge current | 6A | |
| Maximum continuous discharge power to cutoff voltage | 57W | |
| Weight: | 496g, 1lb 2oz | |
| Communications: | Fully SMBus rev 1.1 Compliant | |
| Data System: | Fully SBDS rev 1.1 compliant | |
| Charging: | Inspired Energy "CH" range desktop charger or other SMBus Level 3 compliant charger (Linear Tech 4100 recommended). | |
| Height: | 22.3 mm, 0.9" | |
| Length: | 214.6 mm, 8.5" | |
| Width: | 58.9 mm, 2.4" | |
| Recommended battery cavity: | 23.5mm x 60mm cross section. The battery should be centered within this cavity. | |
| Engineering Data Sheet | Battery NI2040ED29 spec v1.1.pdf | |

## 7. Specifications for the Reuter-Stokes $^{3}He$ Proportional Gas Tubes

| | |
|---|---|
| Model Number: | SA-P4-0815-105 |
| Mechanical | |
| Maximum diameter: | 1.03 in (26.2 mm) |
| Maximum overall length: | 17.03 in (432.6 mm) |
| Maximum weight: | 200 g |
| Material | |
| Body material: | 1100 aluminum |
| Internal insulator: | alumina ceramic |
| Primary gas: | $^{3}He$ |
| Total pressure: | 150 psia (1.03 MPa) |
| Electrical | |
| Resistance: | $1.00 \times 10^{12}$ ohms |
| Capacitance: | 8 pf ±20% |
| Maximum Ratings | |
| Maximum Voltage: | 2500 volts |
| Maximum Temperature: | 100°C |
| Operating Characteristics | |
| Thermal neutron flux range: | $9.2 \times 10^{-4}$ to $7.72 \times 10^{2}$ nv |
| Thermal neutron sensitivity: | 66 cps/nv ± 10% |
| Voltage Range: | 1200 to 1700 volts |
| Resolution (FWHM): | < 12 % |
| Temperature range: | -25 to 100 °C |

## 8. Reference


[1] C. E. Moss, S. M. Gonzales, J. D. Hutchinson, G. E. McKenzie IV, W. L. Myers, R. B. Rothrock, S. A. Salazar, M. A. Smith-Nelson, E. R. Sorensen, G. M. Sundby, "Field Guide for Active Interrogation (U)," LANL report LA-UR-17-22226, issued 2017-03-16.

**Appendix A**

## *.lmx File format revised 3-12-13

The List Mode eXtension (LMX) file format consists of two parts; a header section that contains information about the data collection and a binary section that contains the list mode data in binary format.

### Header

The header section is in text (ASCII) for easy readability. Multiple spaces may exist at the end of each header line to pad each line to a specific number of characters. Each header line must end with carriage return <u>and</u> line feed (ASCII Codes = 13/10. Hex 0D 0A, format \r\n)

Each line of the header has three parts; a name, the associated value, and units if applicable and takes the form:

*keyword* : *value* [*units*]

If values have units, they must be present within brackets. If units are not applicable this term is not present.

Not all header lines need to be present and they do not need to be in any specific order (except for "ListModeExtensionFileVersion" must be first line and BinaryDataFollows must be the last line as described below.) Mandatory lines are indicated in Table 1. The file may include unique header lines as long as they do not duplicate the keywords in Table 1.

The header names are case sensitive in order to maintain consistency with the *.cmx file (the condensed file format).

Table 1. List of Header Keywords

| Name | Value type | [Units] | Example Values | Mandatory | Comments |
|---|---|---|---|---|---|
| ListModeDataFileVersion | string | | 1.01 | Y | This tag must be first in the file |
| InstrumentType | string | | Neutron Multiplicity | | |
| InstrumentModel | string | | MC15 | Y | |
| SerialNumber | string | | S/N 026 | | |
| HardwareVersion | string | | 006 | | |
| FirmwareVersion | string | | aa4f717 | | |
| CCodeVersion | string | | 90073114 | | |
| LCDVersion | string | | 1.1.0.184 | | |
| MeasurementID | string | | 2012_05_30_143526 | | |
| MeasurementDescription | string | | Run 10A | | Entered on LCD |
| MeasurementSample | string | | 1 of 30 | | Run number is a sequence |
| MeasurementMode | string | | Multiple | | MC-15 configuration: single or multiple |
| FrontPanelConfig | string | | Together | | Front panel configuration: together, separate, missing |
| AnalysisChannels | hex | | 0x00007FFF | | Channels used in real time analysis and cmx file creation |
| DateStart | string | YYYY-MM-DD[Z] | 2012-05-30 [Z] | Y | Date of start of assay |
| TimeStart | string | Hrs:min:sec | 14:35:26 [Z] | Y | Time the assay was started |
| DurationRealTime | positive real | s | 600 [s] | | Duration of assay |
| EndOfAssayStatus | string | | Normal | | Normal, Cancelled by user, Cancelled by file size limit |
| InternalScaler | real | | 5000 | | Counts recorded in firmware during assay |

| | | | | | |
|---|---|---|---|---|---|
| FiFoLostCounts | real | | 0 | | Number of counts not read from firmware |
| AverageCountRate | real | Counts/s | 8.33 [counts/s] | | Calculated after assay.<br>Internal Scaler/duration |
| DistanceDetFaceToSource | real | cm | 23.5 [cm] | | “unknown” if not entered |
| DistanceDetCenterToFloor | real | cm | 0.0 [cm] | | “unknown” if not entered |
| HighVoltageSetPoint | real | V | 1600 [V] | | |
| HighVoltageActual | real | V | 1598 [V] | | |
| TemperatureCPU | string | C | 78 [C] | | Temperature of FPGA surface |
| TemperatureLCD | string | C | 78 [C] | | Temperature of LCD unit |
| TemperatureInternal | string | C | 78 [C] | | Temperature of instrument air |
| HumidityInternal | real | % RH | 38 [%] | | % relative Humidity inside instrument |
| BarometerElevation | real | meters | 2146 [m] | | Not compensated |
| FirmwareChannelDeadtime | Real | Nanoseconds | 1000 [ns] | | Time interval that a second event on a channel cannot be recorded |
| RowRatio(1/2) | real | | 1.01 | | Front row/middle row |
| RowRatio(1/3) | real | | 0.988 | | Front row/back row |
| RowRatio(2/3) | real | | 0.938 | | Middle row/back row |
| | | | | | |
| | | | | | |
| Comment | | | | | |
| | | | | | |
| BinaryDataEventSizeInBytes | Integer | | 8 | | Number of bytes that make up every event |
| BinaryDataChannelFormat | string | | unsigned int32 | | |
| BinaryDataClockFormat | string | | unsigned int32 | | |
| BinaryDataClockTickLength | ns | | 100 [ns] | | Time interval each clock tick represents |
| BinaryDataActiveChannels | hex | | 0x00007FFF | | Channels input to firmware |
| BinaryDataFollows | | | | Y | Binary data start immediately after a line feed/carriage return (ASCII codes = 13/10) |

Here are the 3 possible "EndOfAssayStatus" states that are written into the lmx header. Only 1 will appear.

EndOfAssayStatus : Cancelled by file size limit
EndOfAssayStatus : Cancelled by user
EndOfAssayStatus : Normal

Cancelled by file size limit happens automatically in software.
Cancelled by user happens when, you guessed it, the user pushes the cancel button.
Normal happens when time expires according to "DurationRealTime" being reached.

If the assay is cancelled, "DurationRealTime" is adjusted to the actual end time. It may have started out at 1000s or something, but is written as the actual end time.

Here is an example of the latest version of the lmx header (when file size limit was reached). (Required lines are in Red)

ListModeDataFileVersion : 2.01
InstrumentType : Neutron Multiplicity
InstrumentModel : MC-15
SerialNumber : S/N 007
HardwareVersion : 6a
FirmwareVersion : 1bdf0417
CCodeVersion : 10170417
LCDVersion : 1.0.0.182
MeasurementID : 2017_04_27_110748
MeasurementDescription : ULTRA HIGH C-252 TEST
MeasurementSample : 1 of 100
MeasurementMode : Multiple
FrontPanelConfig : Together
AnalysisChannels : 0x7FFF7FFF
DateStart : 2017-04-27 [Z]
TimeStart : 11:07:48 [Z]
DurationRealTime : 174 [s]
EndOfAssayStatus : Cancelled by file size limit
InternalScaler : 271198097

| | |
|---|---|
| FifoLostCounts | : 0 |
| AverageCountRate | : 1558609.88 [counts/s] |
| DistanceDetFaceToSource | : 0.0 [cm] |
| DistanceDetCenterToFloor | : 0.0 [cm] |
| HighVoltageSetPoint | : 1680 [V] |
| HighVoltageActual | : 1682 [V] |
| TemperatureCPU | : 39 [C] |
| TemperatureLCD | : 0 [C] |
| TemperatureInternal | : 33 [C] |
| HumidityInternal | : 16 [%] |
| BarometerElevation | : 2289 [m] |
| FirmwareChannelDeadtime | : 1000 [ns] |
| RowRatio(1/2) | : 0.909 |
| RowRatio(1/3) | : 1.353 |
| RowRatio(2/3) | : 1.489 |
| Comment | : If all channels are zero, this indicates channels |
| Comment | : in next event is a flag (not a real event) |
| Comment | : Flag = 0x00000001 (Clock rollover occurred) |
| Comment | : Flag = 0x00000002 (Gate input started) |
| Comment | : Flag = 0x00000003 (Gate input ended) |
| Comment | : Flag = 0xFFFFFFFF (End of binary data) |
| BinaryDataEventSizeInBytes | : 8 |
| BinaryDataChannelFormat | : unsigned int32 |
| BinaryDataClockFormat | : unsigned int32 |
| BinaryDataClockTickLength | : 100 [ns] |
| BinaryDataActiveChannels | : 0xFFFFFFFF |
| BinaryDataFollows | : |

## Binary data

The binary section of data is started with the tag

BinaryDataFollows : n number of spaces \r\n Binary data start immediately after a carriage return/line feed (ASCII codes = 13/10)

Format of Binary Data: [Channel Data] [Time]

Channel Data and Time are written in little endian, i.e., least significant byte first.

Insertion of specific flags/codes into Binary Data:

A flag is captured in 2 event records. The event size in bytes is defined in the header section (BinaryDataEventSizeInBytes : ). All zeros in every channel indicate that the next event is a flag (not a neutron event). The all-zero channel data is paired with the time tag associated with the flag occurrence. The next event describes the flag type and is paired with the same time tag.

Examples: Flag = 1: Clock rollover occurred
Flag = 2: Hardware veto/gate started
Flag = 3: Hardware veto/gate ended
Flag = FFFFFFFF : End of File indicator

Clock Rollover: 00000000FFFFFFFF (all zeros in channels along with maximum clock tic before rollover)
00000001FFFFFFFF (flag type 1 in channels along with maximum clock tic before rollover)

End of File: 000000001B037AD1 (all zeros in channels along with clock tic at end of assay)
FFFFFFFF1B037AD1 (flag type FFFFFFFF in channels along with clock tic at end of assay)

**Appendix B**

## Example of CMX Data File


```xml
<CondensedNeutronDataFile version="1.07">
  <InstrumentInformation>
    <InstrumentType>Neutron Multiplicity</InstrumentType>
    <InstrumentModel>MC-15</InstrumentModel>
  </InstrumentInformation>
  <MeasurementData type="multiplicity" sample="1 of 1">
    <MeasurementID>2015_09_28_080322</MeasurementID>
    <MeasurementDescription>No Description Provided</MeasurementDescription>
    <StartTime>2015-09-28T08:03:22 Z</StartTime>
    <RealTime units="s">300</RealTime>
    <FIFOLostCounts>0</FIFOLostCounts>
    <DetectorInformation>
      <SerialNumber>S/N 007</SerialNumber>
      <HardwareVersion>005</HardwareVersion>
      <FirmwareVersion>aa9f0703</FirmwareVersion>
      <CCodeVersion>29000723</CCodeVersion>
      <LCDVersion>167e</LCDVersion>
      <MeasurementMode>Multiple</MeasurementMode>
      <FrontPanelConfig>Together</FrontPanelConfig>
      <ActiveChannels>0xFFFFFFFF</ActiveChannels>
      <AnalysisChannels>0x7FFF7FFF</AnalysisChannels>
      <DistanceDetectorFaceToSourceCenter units="cm">30.0</DistanceDetectorFaceToSourceCenter>
      <DistanceDetectorCenterToFloor units="cm">22.0</DistanceDetectorCenterToFloor>
      <TemperatureCPU units="C">61</TemperatureCPU>
      <TemperatureLCD units="C">36</TemperatureLCD>
      <TemperatureInternal units="C">0</TemperatureInternal>
      <HumidityInternal units="percent">42</HumidityInternal>
      <HighVoltageSetPoint units="V">1680</HighVoltageSetPoint>
      <HighVoltageActual units="V">1680</HighVoltageActual>
      <BarometerElevation units="m">0</BarometerElevation>
```

<FirmwareChannelDeadtime units="ns">100</FirmwareChannelDeadtime>
</DetectorInformation>
<ProcessedNeutronData>
<CountHistory channelmask="0xFFFFFFFF">
<Interval units="s">1</Interval>
<CountData>9006 9148 9084 9183 9258 9299 9124 9087 9097 9179 9230 9159 9043 9221 9027 9094 9121 9022 9082 8971 8776 8797 8946 8827 9352 9079 9259 9175 9111 9003 9050 9209 9101 9312 9149 9179 8972 9179 9080 9357 9125 8881 9136 9079 9146 9038 9144 9147 9089 8959 8884 9217 9010 9087 9219 9056 9185 9154 9059 9183 8998 9116 9314 9154 9218 9272 9143 9067 9201 9076 9181 9149 9063 9227 9051 9088 9229 9168 9184 9238 9246 9099 9066 9318 8969 8962 9195 9059 9170 9020 9190 9141 9174 8986 9079 9075 9210 8952 9039 9173 8994 9161 9232 8991 9155 9163 9188 9046 9280 8886 8916 9177 9104 9118 9219 9070 9115 8995 9064 9241 9124 9073 9084 9015 9013 9177 9031 9104 8792 8642 8878 8623 8785 8764 8914 9137 9068 9202 9276 9106 8963 9224 9016 8933 9116 9034 9070 9226 8942 9084 9193 9155 9095 9336 9024 9226 9167 9085 8925 9221 9101 9109 9062 9081 9038 9040 9060 9235 9117 9196 9161 9064 9261 9020 9188 9145 8917 9342 9214 9142 8886 9017 9192 9181 9331 9064 9180 9024 9098 9166 9049 9147 9075 9033 9021 9147 9111 9152 9056 9067 9254 8859 9283 9173 9209 9172 9071 9096 9250 9105 9151 9115 9104 8941 8890 8946 8979 9048 9115 9122 9249 9113 9061 9248 9279 9035 9072 9197 9141 9083 9152 9118 8998 9306 8951 9226 8949 9014 9116 9158 9033 9167 9064 8974 8990 9266 9127 9278 9060 9263 9035 9105 9198 9163 9181 9178 8860 9058 9033 8961 8967 9276 9077 9080 9165 9151 9072 9183 9194 9146 9031 9074 9083 8885 8877 9181 9079 9146 9022 9357 9274 8876 8997 9005 9237 8998 9032 9092 9278 9097 9131 8877 9084 9191 9104 9068 9092 9171 9152 9124 </CountData>
</CountHistory>
<RowRatio>
<ChannelsUsedInRowOne>2 3 5 6</ChannelsUsedInRowOne>
<ChannelsUsedInRowTwo>9 10 11 12</ChannelsUsedInRowTwo>
<ChannelsUsedInRowThree>14 15</ChannelsUsedInRowThree>
<RowOneOverTwoRatio>0.678</RowOneOverTwoRatio>
<RowOneOverThreeRatio>1.053</RowOneOverThreeRatio>
<RowTwoOverThreeRatio>1.554</RowTwoOverThreeRatio>
</RowRatio>
<GrossCounts channelmask="0xFFFFFFFF">
<TotalCounts>2730123</TotalCounts>
<RealTime units="s">300</RealTime>
<AverageCountRate units="counts/s">9100.41</AverageCountRate>
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